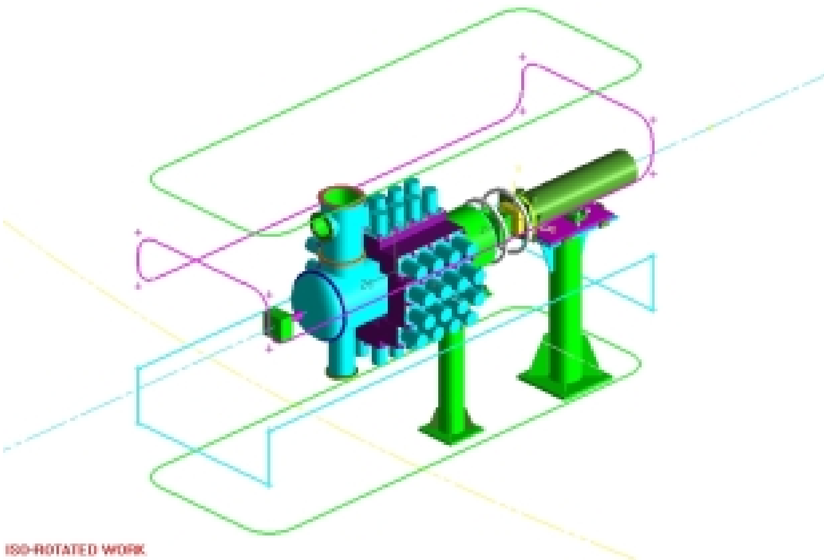
$n+p \rightarrow d + \gamma$ at SNS;
Clean Measurement of H_π^1



Seppo Penttila
P-23, LANL

Based on the work of the NPDGamma Collaboration

FPSNS-2001
Oak Ridge
Sep-20-2001

Los Alamos

Parity-Violating Gamma Asymmetry in n+p->d+γ

- n+p->d+γ experiment measures parity-violating gamma asymmetry A_γ in capture of polarized cold neutrons by para-H_2.
- Expected asymmetry $A_\gamma \leq 5 \times 10^{-8}$
- Goal experimental error is 0.5×10^{-8}
- $A_\gamma \approx - 0.045 H^1{}_\pi$
- A clean measurement of $H_\pi{}^1$; 2-body system - no nuclear structure uncertainty

Measurement of the Parity-Violating Gamma Asymmetry A_γ in the Capture of Polarized Cold Neutrons by Para-Hydrogen, $n + p \rightarrow d + \gamma$

NPDGamma Collaboration

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E.I. Sharapov

Joint Institute for Nuclear Research, Dubna

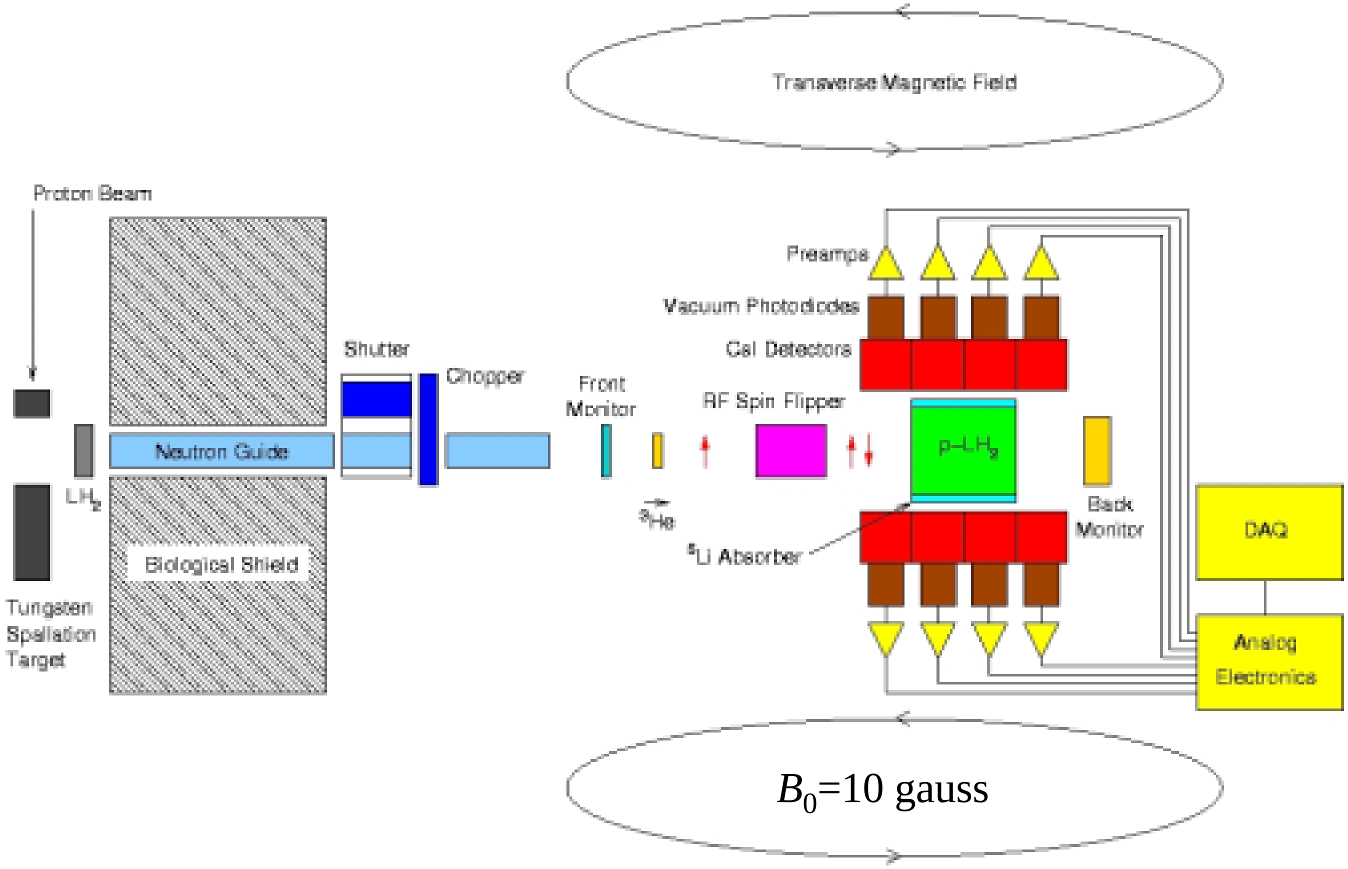
http://p23.lanl.gov/len/npdg/

The n+p->d+γ Experiment is Designed for Pulsed Cold Neutrons

The experimental error of 0.5×10^{-8} is a challenge for the polarized cold neutron flux from a spallation source as well as for the control of systematic errors.

- To reach the statistics we need about 4×10^{17} neutrons.
- Use of time-of-flight allows design of an experiment with systematic errors less than 0.5×10^{-8}.

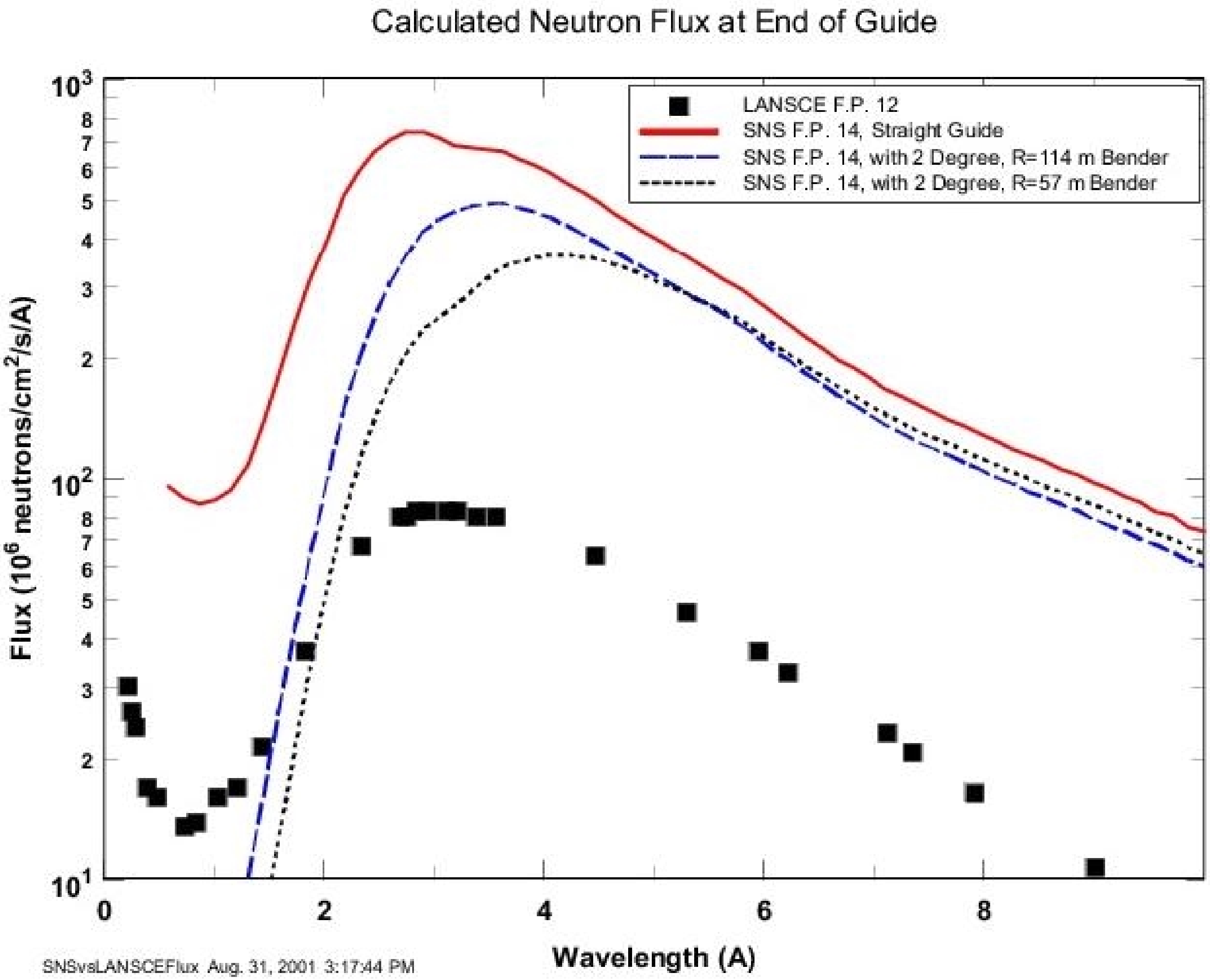
NPDGamma Experiment



$$d\omega/d\Omega = 1/4\pi(1+A_\gamma \cos(\Theta_{\mathbf{s}_n \cdot \mathbf{k}_\gamma}))$$

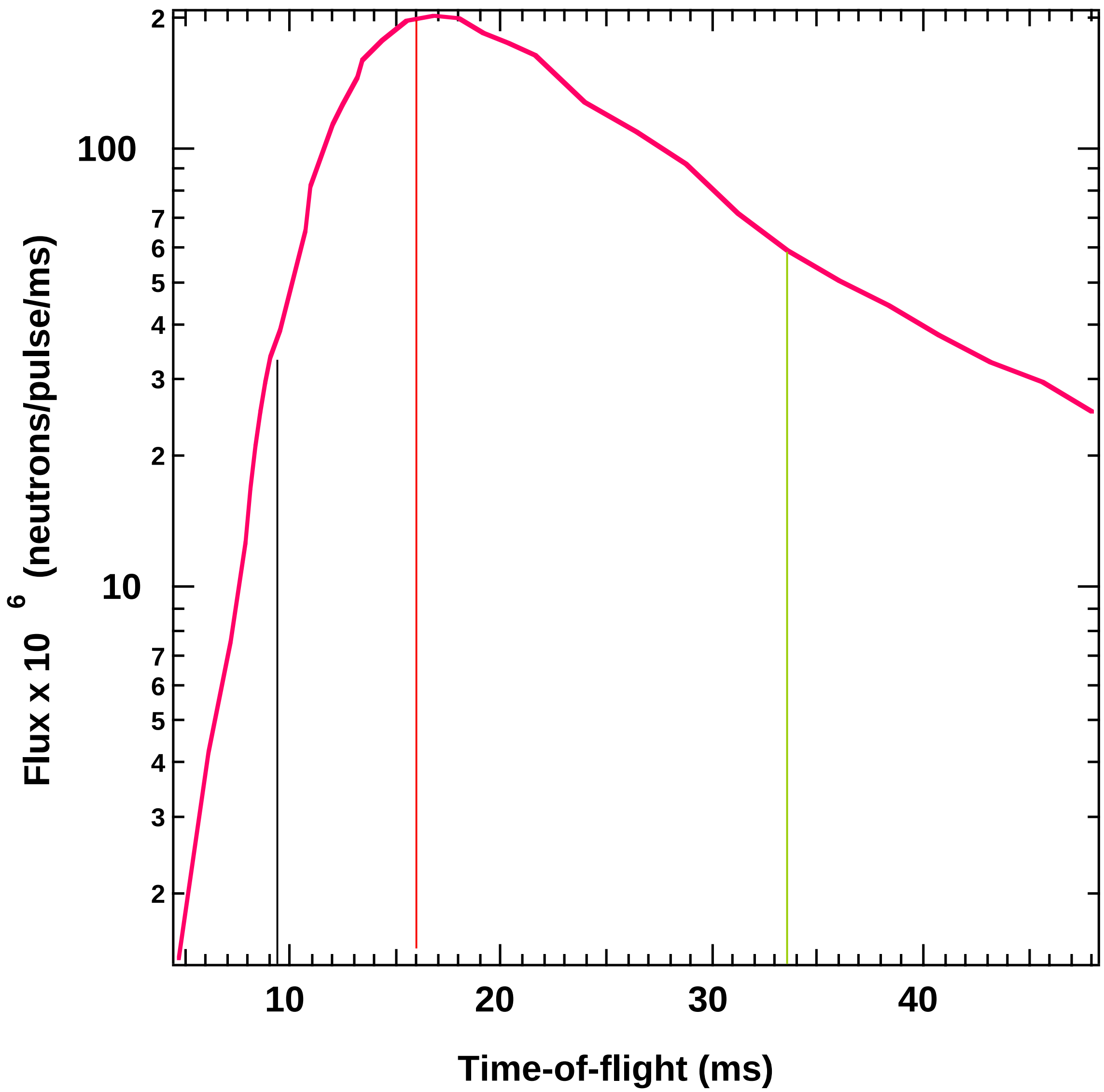
n+p->d+γ Experiment on BL14B at SNS

- SNS is 1.44-MW spallation source with rep. rate of 60 Hz.
- As a comparison, the LANSCE source is 0.16 MW with rep. rate of 20 Hz
- BL14B at SNS will have a neutron guide with
    - Cross section of 10cm x 12cm
    - Length of 15m
    - Reflectivity of Θ_c=3.5
    - 2-degree - R=114 m bender. Fast neutrons (E>80 meV) and γ's from the source are filtered -> small backgrounds and light radiological shielding.
- Additional assumptions for n+p->d+γ:
    - Frame definition chopper at 10 m
    - Experiment at 19 m



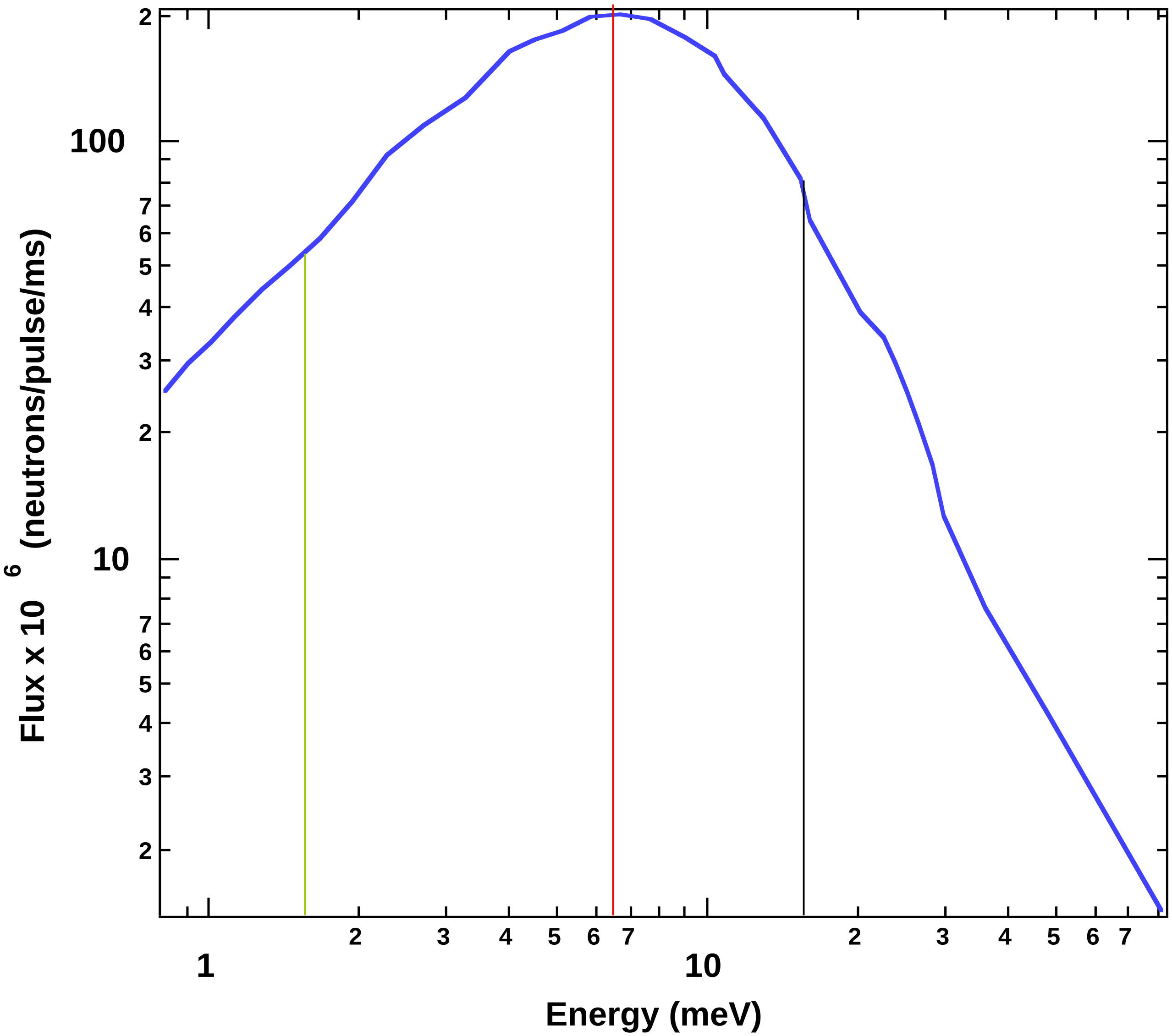
Calculated Neutron Flux at End of Guide
LANSCE F.P. 12
SNS F.P. 14, Straight Guide
SNS F.P. 14, with 2 Degree, R=114 m Bender
SNS F.P. 14, with 2 Degree, R=57 m Bender
Flux (10^6 neutrons/cm^2/s/A)
Wavelength (A)
SNSvsLANSCEFlux Aug. 31, 2001 3:17:44 PM

Frame Issue: 60 Hz vs 30 Hz



E(meV)	15	3.8	1.7	0.9
λ(A)	3.3	4.6	7.0	9.5

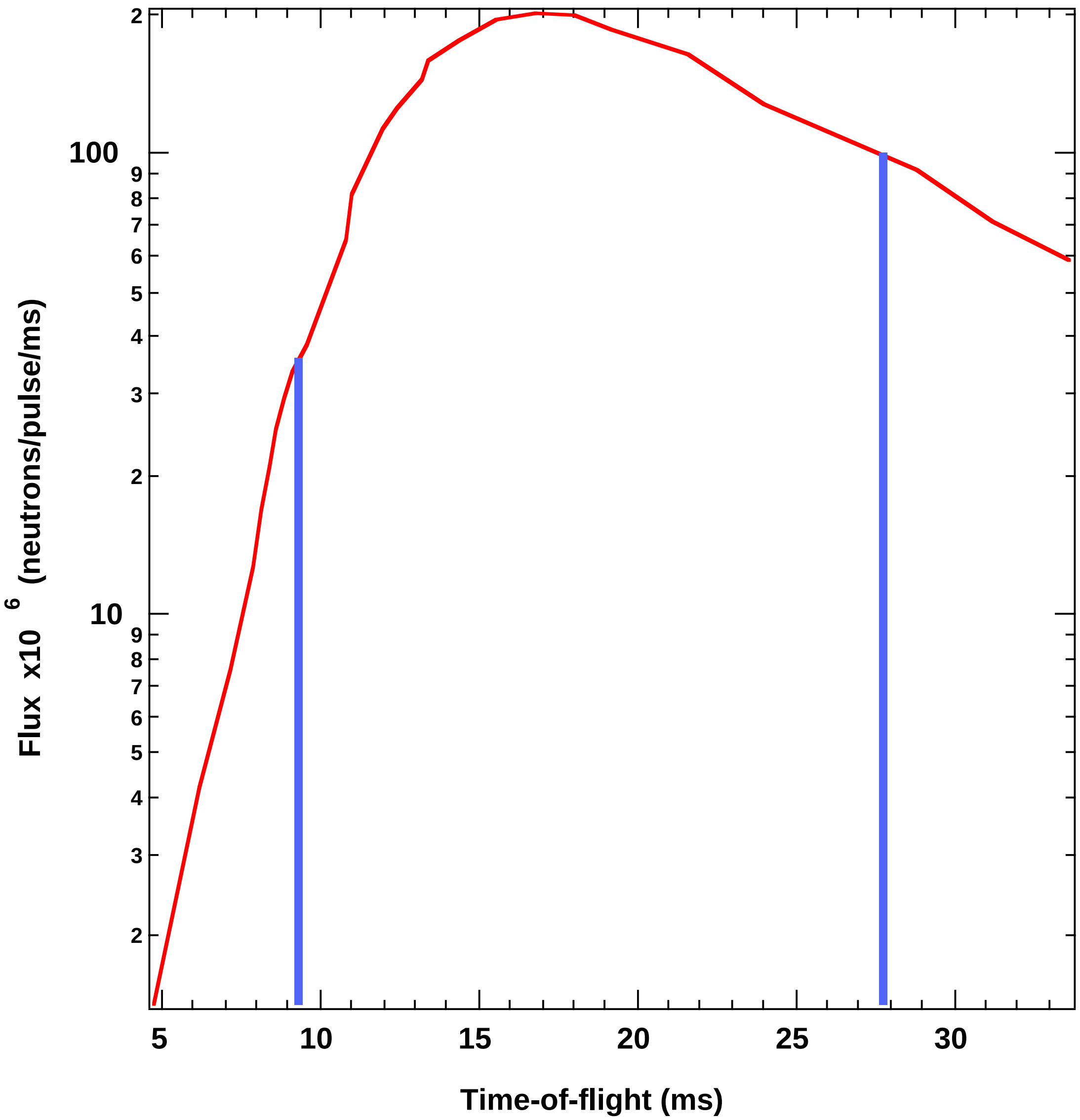
Frame Issue: 60 Hz vs 30 Hz



Frame Issue:
Number of neutrons in 60-, 30- and 20-Hz frames

Frame (Hz)	TOF window (ms)	Neutrons/sec x 10^{10}
60	10-17	6
30	10-33	9
20	10-48	7

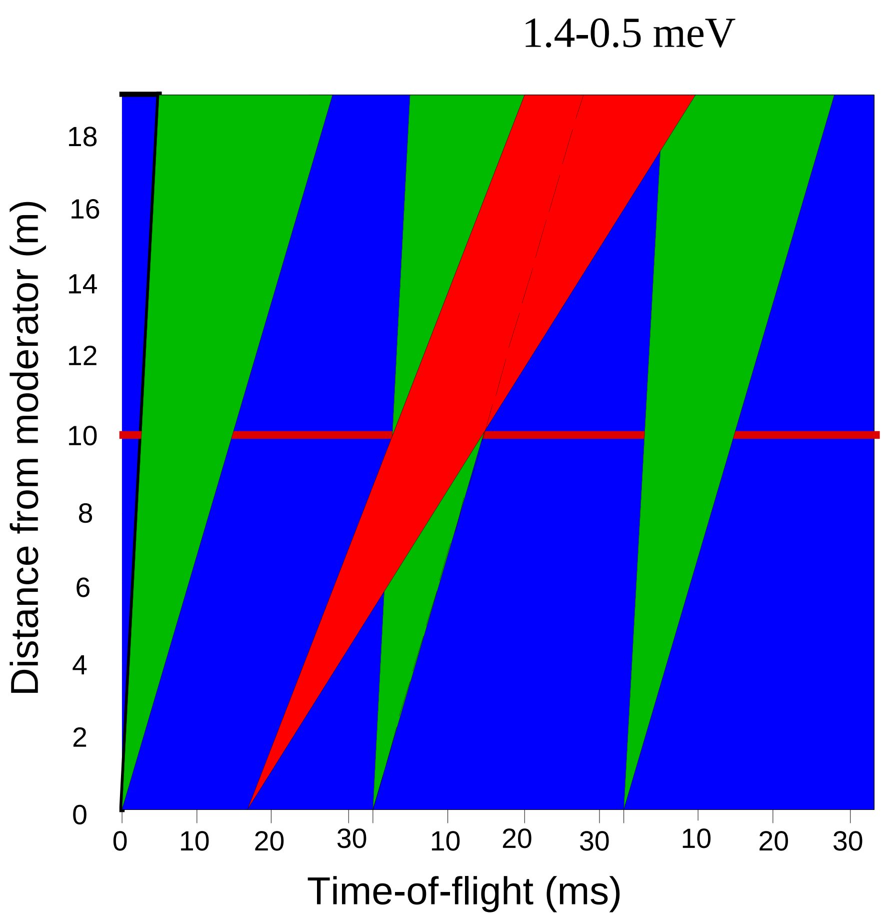
n+p->d+γ with 30-Hz Frame

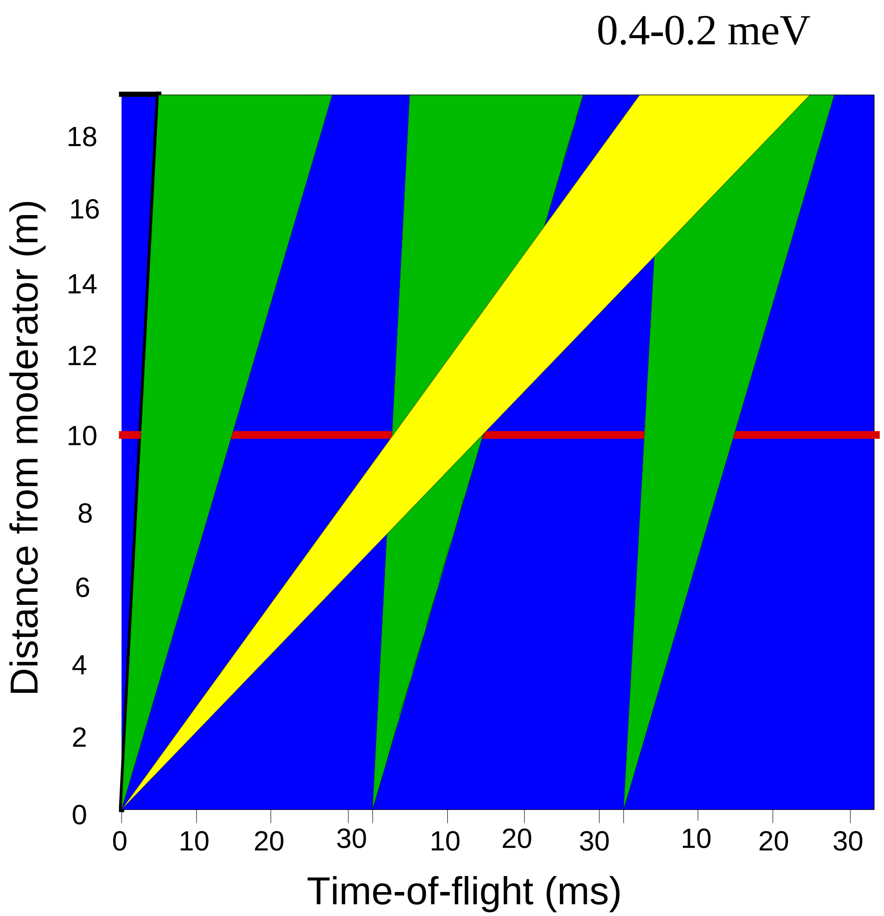


x10^6

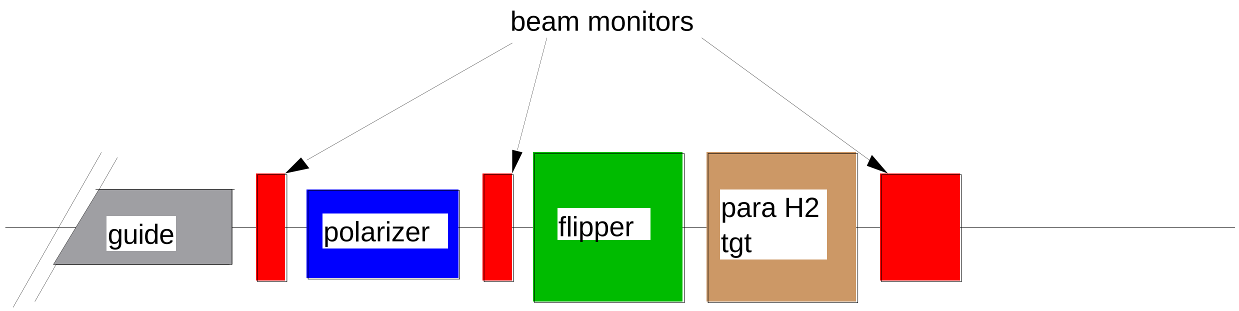
3139
58
2654
427

30-Hz Frame; frame overlaps





Neutron Beam Monitors



- Commercial fission chambers
- Thickness - 1% beam attenuation at 4meV
- Accuracy - 1% flux measurement
- Diagnostics
  - With two chambers polarization measurement *via* transmission
  - Measurement of ortho-para ratio in the target.

Neutrons Polarized by Optically-Polarized ^{3}He Spin Filter

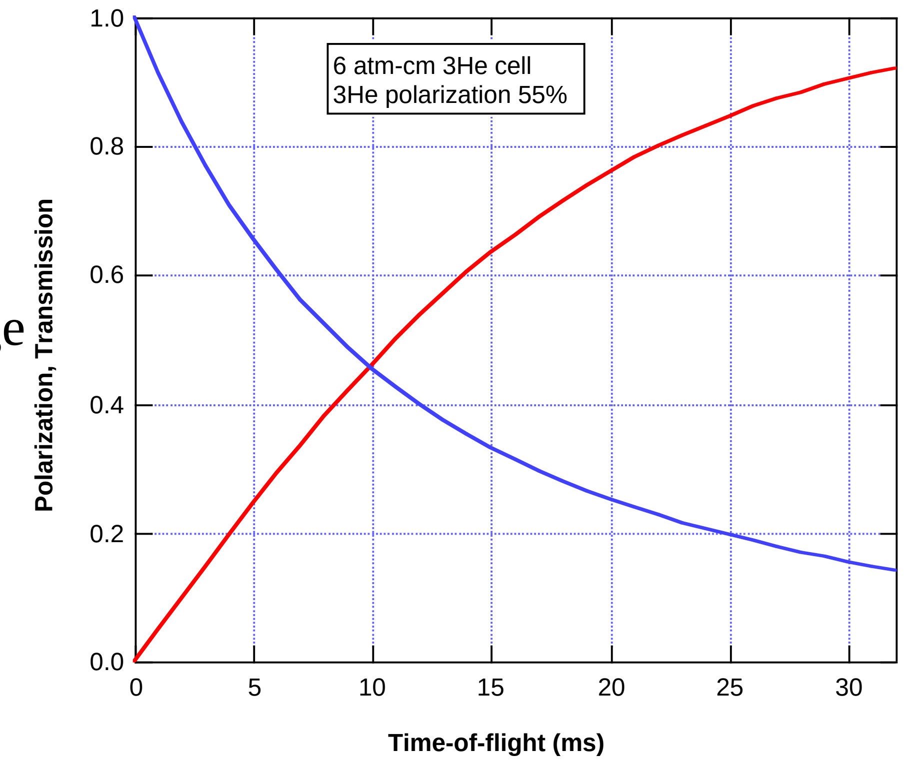
$$P_n = \tanh[nl\sigma_p(E_n)P_{He}]$$

$$T_n = T_n^0 \cosh[nl\sigma_p(E_n)P_{He}]$$

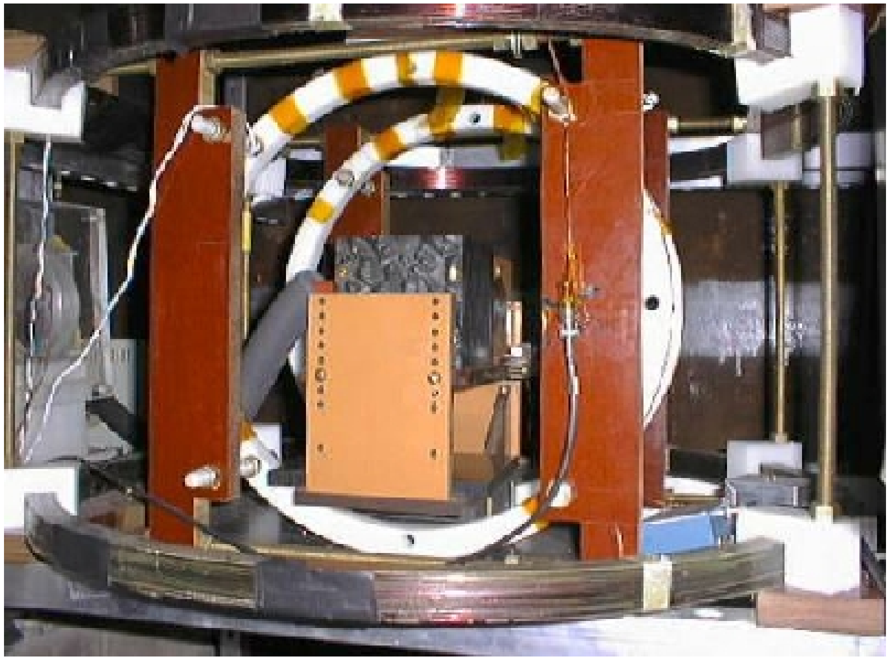
$$P_n=(1-(T^0_n/T^p_n)^2)^{1/2}$$

^{3}He neutron spin filter:

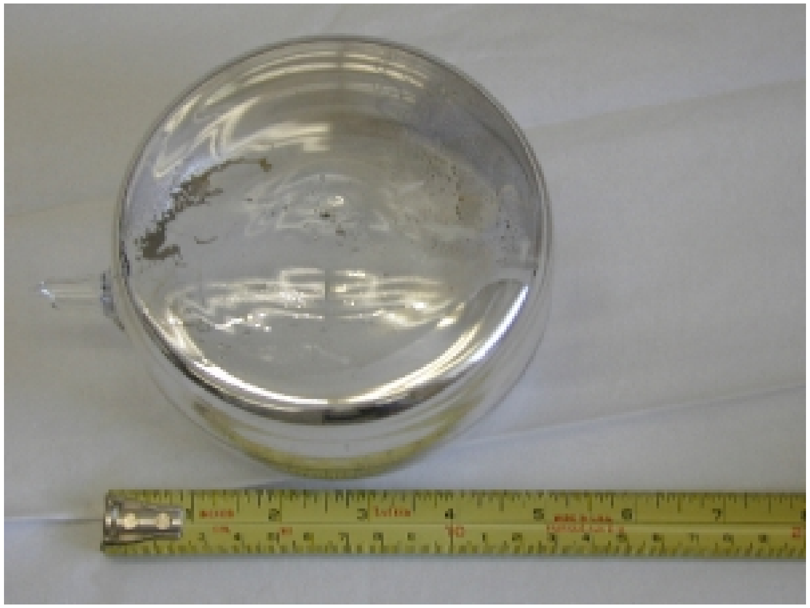
- In a ^{3}He cell Rb atoms are polarized by laser light. Through spin exchange ^{3}He gas is nuclear polarized.
- Cross section of the n-^{3}He singlet state is much larger than the triplet state.
- Therefore, neutrons with spin antiparallel with ^{3}He spins are absorbed and neutrons with spin parallel with ^{3}He spins are transmitted -> neutron spin filter



^{3}He Spin Filter Set Up



NPDGamma NIST collaborators have fabricated 12-cm in diameter cells. The best cell has T_1> 500 hr. ^{3}He polarization 50% has been measured.



- Large area, 12 cm in dia, ^{3}He cells are required to cover the beam.
- Along the beam about 10”-12” space for ^{3}He spin filter is required.
- ^{3}He spin filter allows a compact experimental setup.
- ^{3}He spin filter offers an extra spin flip without a field change.

Class 4 laser - P_{light}≈100 W

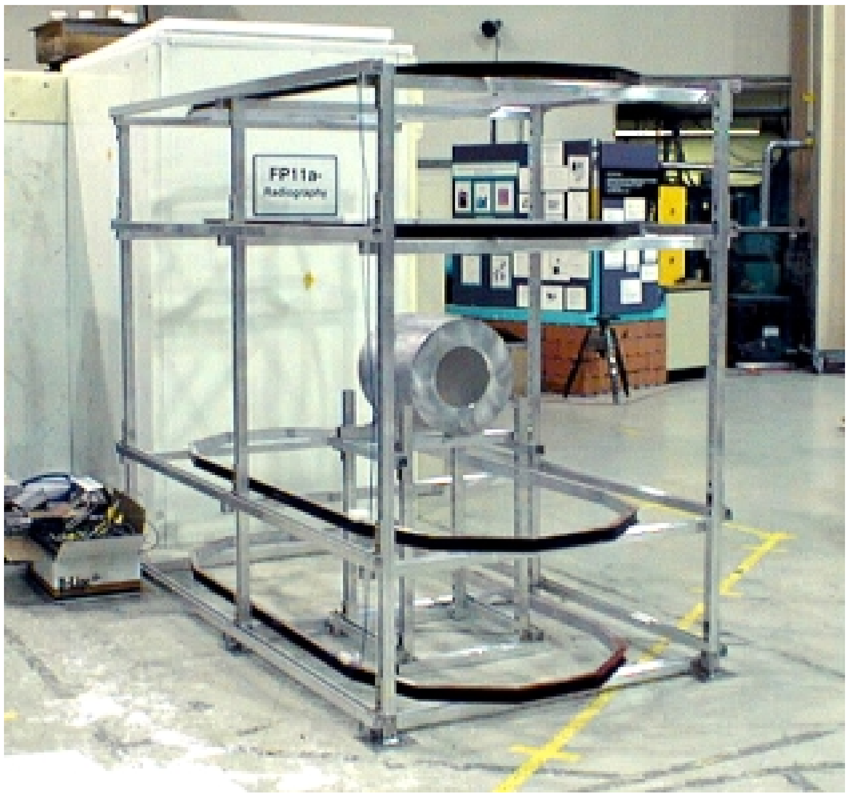
RF Spin Flipper

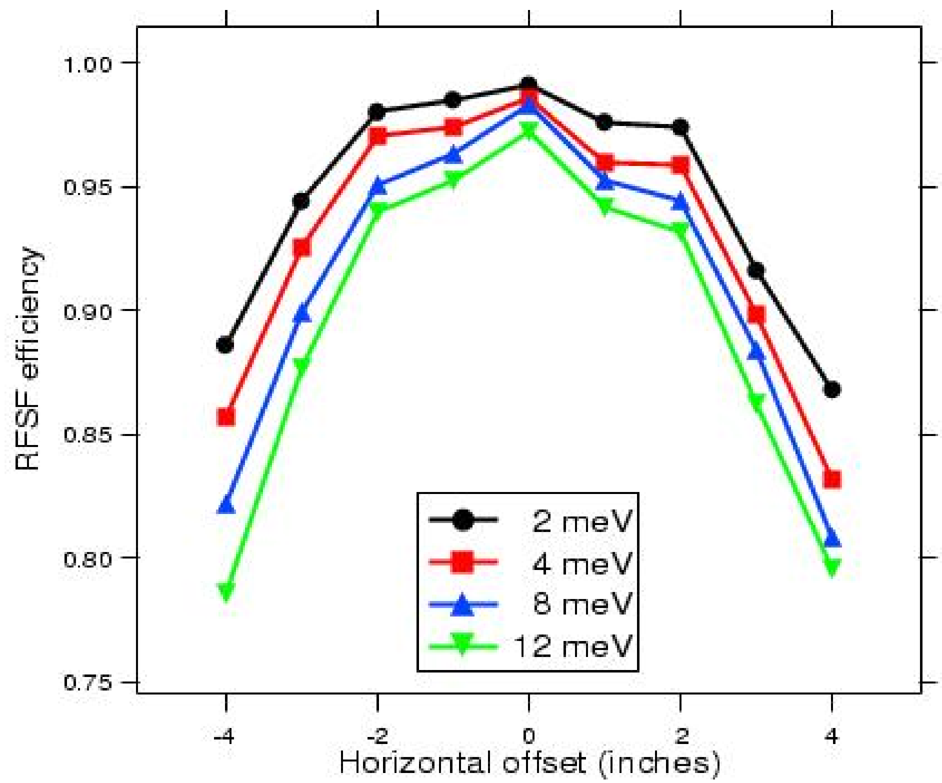
- RF spin flipper is the main control of systematic errors.
- External field $B_0 = 10$ gauss.
- Magnetic gradients < 1 mgauss/cm - no Stern-Gerlach steering.
- Spin reversal with a RF spin flipper.
  - E_n is proportional to $1/(\mathrm{tof})^2$
  - In NMR at resonance $\Theta = \gamma B_1 \Delta t$
  - To precess a neutron spin by π

    $$B_1 = (L/\gamma d)(1/tof)$$

  - Spin-flip efficiency > 95% on axis at the energy range of interest.
- Neutron spin flip possible at 30Hz.

RF Spin Flipper; spin flip efficiency

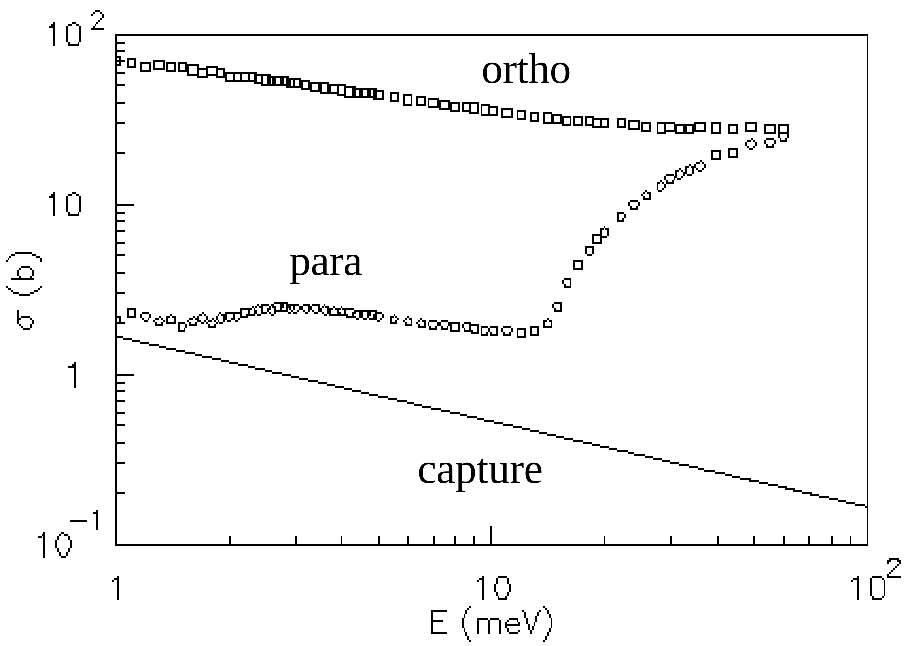




Direction of B_0 has to be known in 5mrad

20-liter Liquid Para-Hydrogen Target

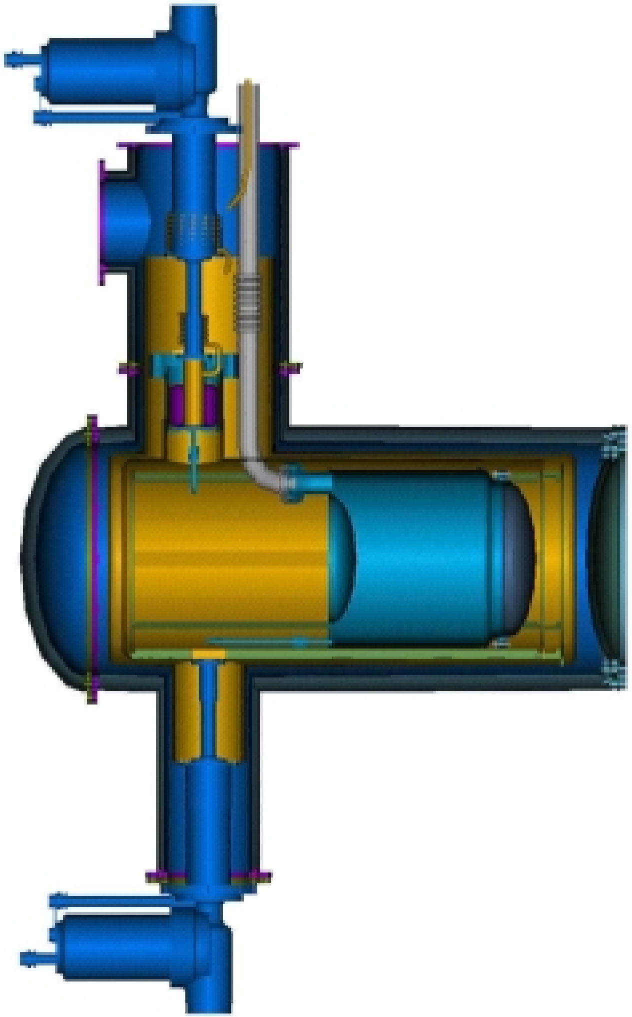
- To maintain neutron spin the para hydrogen target is required.
- The 30cm in diameter and 30 cm long target captures 60% of incident neutrons.
- It has to provide neutron shield for the γ-detectors.
- At 17K only 0.03% of LH_2 is in ortho state -> 1% of incident neutrons will be depolarized.
- Target materials selection so that false asymmetries < 10^{-10}.



Neutron mean free paths at 4 meV for
- n-p ortho λ≈2cm,
- n-p para λ≈20cm
- n-p capture λ≈50cm.

Safe 20-liter Liquid Para-Hydrogen Target

Target under construction at IU by M. Snow

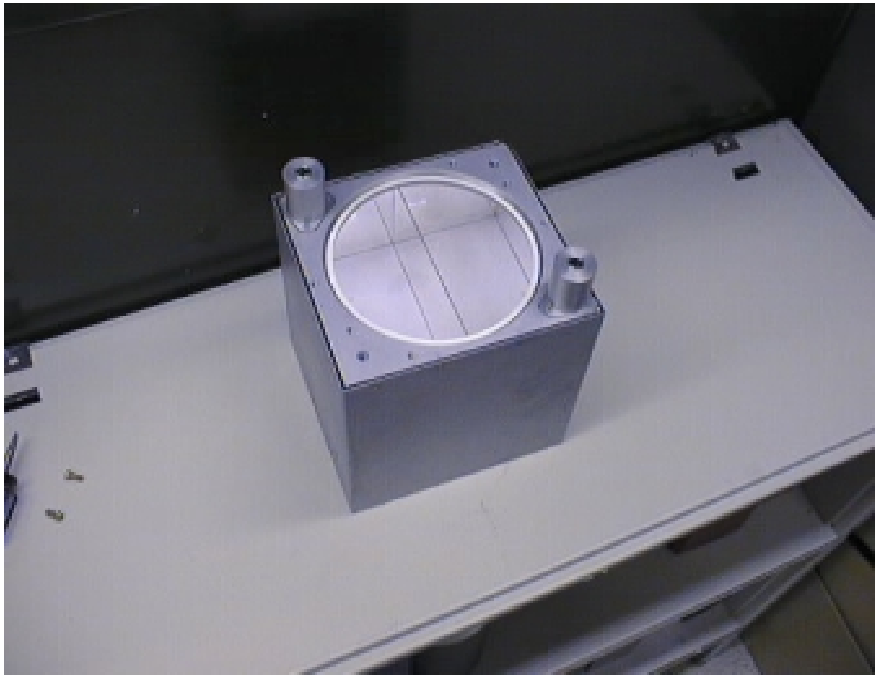


Hydrogen safety !!!!

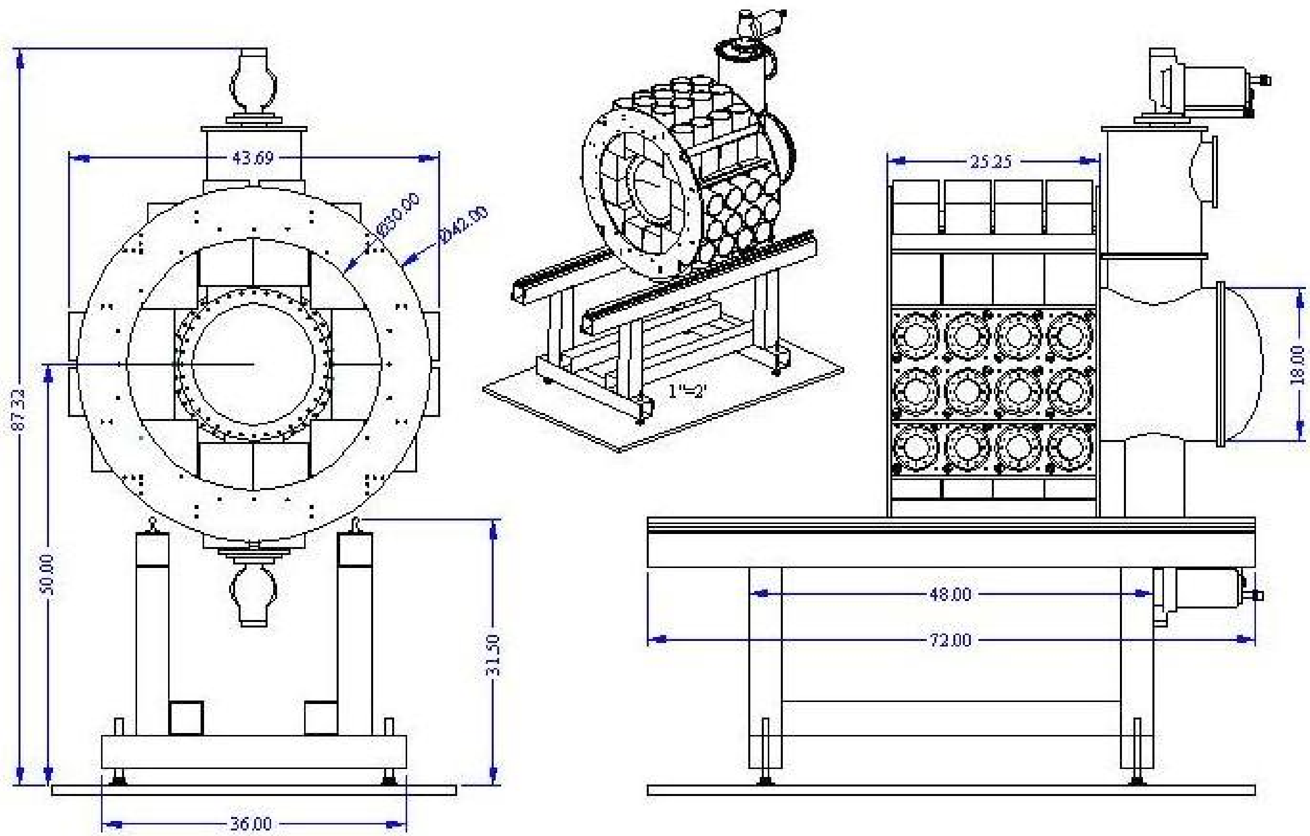
CsI(Tl) Gamma Detector

Detector under construction at IU by M. Snow, contributions from Manitoba, KEK, LANL

- Interaction length of 2.2-MeV γ-ray in CsI is $\lambda \approx 5$cm.
- 48 CsI detectors - 15x15x15cm^3. Total of 0.7 metric ton of CsI.
- 95% of 2.2-MeV γ-rays will be stopped.
- Solid angle coverage of the detector $\approx 3\pi$.



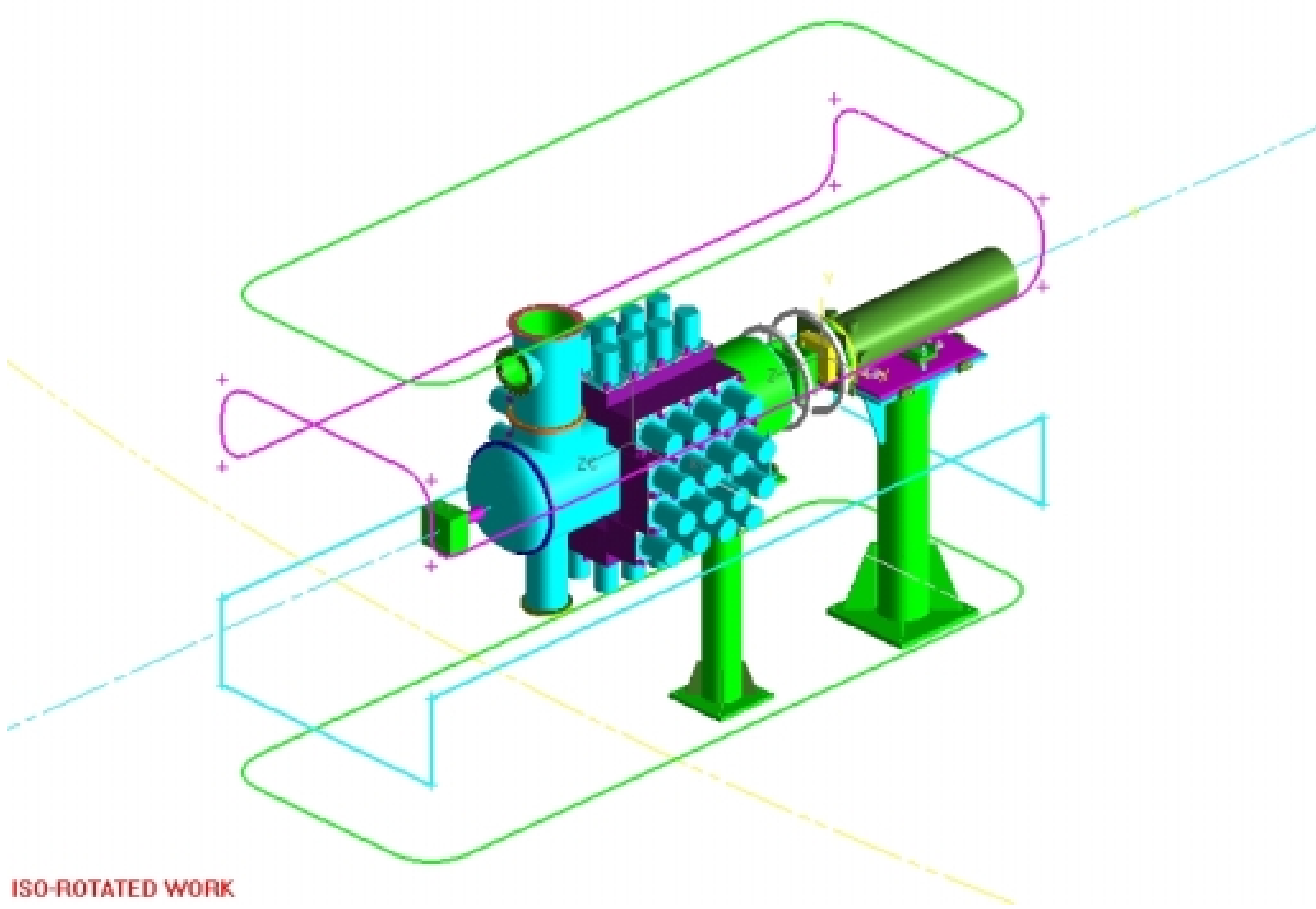
CsI(Tl) Gamma Detector



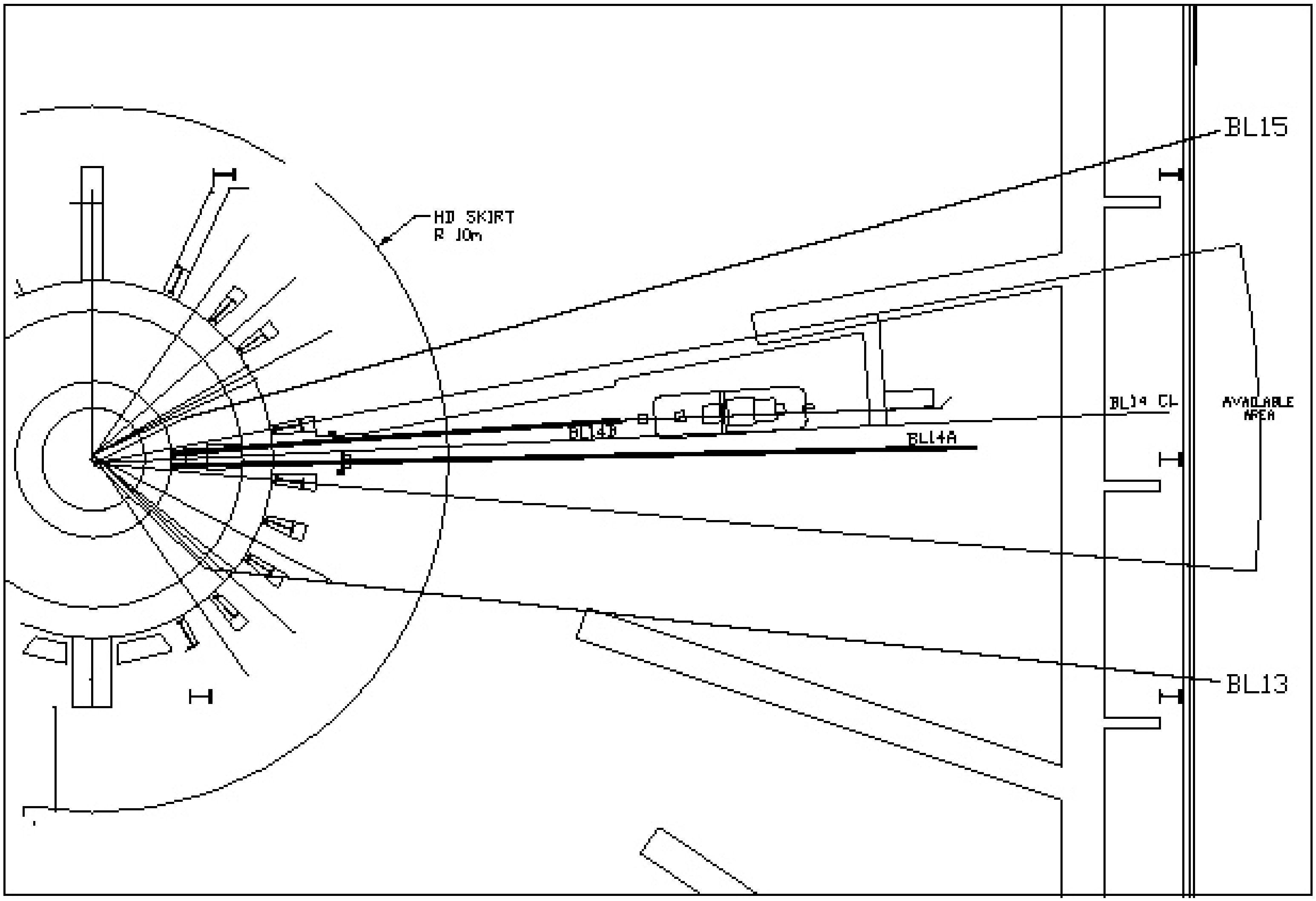
Light detection with vacuum photodiodes

- We will have about $1x10^{11}$n/s -> current mode detection.
- Hammamatsu 3” vacuum photodiodes
  - Linearity < 10^{-4}
  - Magnetic field sensitivity <10^{-4}
- More than 200pe/γ MeV
- We have developed low-noise high-gain preamplifiers.
- Preamp noise < counting statistics/100.

$n+p \rightarrow d+\gamma$ Experiment Layout



n+p->d+γ Experiment Layout



Estimation for Run Time on BL14B

- Integrated flux with 30 Hz is 8×10^{10} n/s for
  tof = 10 - 28 ms.
- ^{3}He transmission, attenuation by matter on beam, LH_2 capture efficiency, detector solid angle,….
  gamma rate = 6.5×10^9 γ/s.
- Run time required for the statistical error of 0.5×10^{-8} is
  6153846 s ≈ 70 days.

Systematic Errors

- Full discussion of systematic errors can be found on http://p23.lanl.gov/len/npdg/.
- Systematic errors are at least one order of magnitude smaller than 0.5×10^{-8}.
- Most of systematic errors correlated with neutron spin have tof dependence.
- SNS FP14B does not introduce any new sources of systematic errors.

Conclusions

- Pulsed polarized cold neutrons are the best way to do the precision $n+p \to d+\gamma$ experiment
  - Experiment can be designed for pulsed cold neutrons.
  - *In situ* control of systematic errors by tof information
- At SNS gamma rates at 30Hz 3-4 times larger than rates at LANSCE FP12 (20Hz).
- At SNS the $n+p \to d+\gamma$ experiment can reach the statistical error of 0.5×10^{-8} in 3 months running.
- The experiment requires a frame definition chopper that handles the frame overlap problem.